Transport-driven sheath instability in magnetic fusion plasmas

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To understand plasma/surface interaction in a fusion reactor, one must know how sheath modifies the characteristics of the upstream plasma as it approaches the wall surface. This is not only important to decipher the wall response to the ion bombardment flux, but also necessary for quantifying inward impurity transport and assessing the fate of dust particulates anticipated in a tokamak reactor. The density and temperature of boundary plasmas in a fusion reactor strongly depend on wall recycling. Of particular recent interest is that the boundary plasma can readily access low-collisionality regime for a low-recycling wall, which can be enabled by flowing liquid lithium or strong pumping. Because of the rapid parallel transport and wall loss, the transit time of an average plasma particle is a distance (in Debye length) divided by the ion sound speed. This becomes comparable to the collision time even at modest temperature.

A consequence of rapid parallel transport that sustains the particle and energy flux to the wall, is that the plasma near the wall will develop a strong temperature anisotropy. This provides free energy that can drive plasma instabilities in the boundary plasma near the wall, which in turn, can modify the plasma transport. Here we carry out a set of comparative studies in the cases of (1) unmagnetized plasma; (2) magnetized plasma with magnetic field intercepting the wall at large angle; and (3) magnetized plasma with B mostly parallel to the wall. Both the physical process for generating and sustaining the temperature anisotropy, and the characteristics of the excited plasma instabilities are investigated by numerical simulation and analytical theory. The role of Weibel instability, whistler wave, and lower hybrid wave will be elucidated for the three reference cases.

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